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RESEARCH MEMORANDUM

FREE-FLIGHT INVESTIGATION OF CONTROL EFFECTIVENESS
OF FULL-SPAN 0.2-CHORD PLAIN AILERONS AT HIGH
SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS
TO DETERMINE SOME EFFECTS OF SECTION
THICKNESS AND WING SWEEPBACK

By

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Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A rocket-propelled test vehicle to be used in an experimental investigation of aerodynamic control effectiveness at high subsonic, transonic, and supersonic speeds has been developed. The test vehicle (RM-5) and the instrumentation are described and the first data obtained are presented. These data indicate some of the effects of section thickness ratio and wing sweepback on the rolling effectiveness of plain full-span 0.2-chord ailerons deflected 5° . For the straight wings tested, decreasing the section thickness ratio from 0.09 to 0.06 decreased the severity of the loss of control effectiveness at transonic speeds. Wing sweepback eliminated the sudden loss of control effectiveness experienced by the straight wings at transonic speeds.

INTRODUCTION

At the present time, there exists a need for experimental information which will assist in the design of adequate aerodynamic controls for use at high subsonic, transonic, and supersonic speeds. Wind tunnels, which heretofore have been the main sources of aerodynamic data, are at the present time incapable of providing reliable aerodynamic data over the entire transonic speed range. Furthermore, supersonic wind-tunnel data to date have usually been of very small scale. A source of experimental aerodynamic control information other than wind tunnels would appear to be required. Wing-flow tests (reference 1) are one such source; however, the small scale of such tests and the limited supersonic speeds attainable present possible limitations to this technique.

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As a result of the foregoing considerations, the Langley Pilotless Aircraft Research Division has undertaken a program to determine experimentally control characteristics in the speed range from high subsonic to supersonic by means of rocket-propelled test vehicles. The exploratory phase of the program is being conducted with the RM-5 test vehicle with which data relating to the rolling capabilities of wing-control combinations are obtained. The RM-5 consists of a pointed cylindrical body at the rear of which are attached wings having preset fixed aileron-type controls. In flight the rolling velocity produced by the ailerons is measured by means of special radio equipment. The rolling velocity measurements, in conjunction with Doppler radar flight-path-velocity measurements and atmospheric data obtained with radiosonde, permit the evaluation of the aileron control effectiveness in terms of the customary parameter $\frac{pb}{2V}$ as a function of the Mach number. The testing technique and the measurements obtained permit the direct evaluation of the rolling capabilities only of the control as part of a wing-aileron combination; however, it is possible to obtain general qualitative information with regard to control effectiveness.

The purpose of the present paper is to describe the RM-5 test vehicle, the instrumentation, and the testing technique and to present data obtained to date. These data indicate some of the effects of wing sweepback and section thickness ratio on the effectiveness of plain-flap type controls over a Mach number range from approximately 0.75 to 1.40.

SYMBOLS

$\frac{pb}{2V}$	wing-tip helix angle, radians
p	rolling velocity, radians per second
b	diameter of circle swept by wing tips, feet
V	flight-path velocity, feet per second
C_D	drag coefficient based on the total exposed wing area of 1.563 square feet
M	Mach number
Λ	wing sweepback

- A aspect ratio (b_1^2/S_1)
- b_1 diameter of circle swept by wing tips minus fuselage diameter
- S_1 exposed area of two wing panels
- c wing chord in free-stream direction
- δ_a control deflection measured in free-stream direction
- I_x moment of inertia about longitudinal axis
- $m_{\theta r}$ wing torsional stiffness parameter (reference 2)
- ϕ ratio of nonrigid wing $\frac{pb}{2V}$ to rigid wing $\frac{pb}{2V}$

DESCRIPTION OF TEST VEHICLE

General

The general arrangement of the RM-5 is shown in figure 1. The models are constructed mainly of wood for ease of construction and lightness. The body is of balsa except at the wing attachment where spruce is used. The wings are constructed of laminated spruce with steel stiffeners inlaid into the upper and lower wing surfaces to provide the required torsional rigidity. The torsional rigidity of the wings is such that the loss of rigid-wing rolling effectiveness due to wing twist does not exceed 20 percent at a Mach number of 0.8. This criterion is considered to be adequate for the purposes of these tests.

A standard 3.25-inch aircraft rocket motor is used for propulsion. This motor was chosen because it provides the speed range required for these tests and is readily available.

Present Tests

In the present tests, the body shape, aspect ratio (3.0), exposed wing area (225 sq in.), taper ratio (1), and the control (0.2c full-span plain flap, $\delta_a = 5^\circ$) were held constant. At zero sweepback NACA 65-009 and NACA 65-006 airfoil sections were tested. The NACA 65-009 section was also tested at 45° sweepback. The airfoil sections

and the control deflections were always taken in the free-stream direction. Photographs of the models tested are shown as figure 2 and a summary of the model configurations tested is given in table I.

Measured wing stiffness values m_{θ_r} and the corresponding rolling effectiveness ϕ expressed in terms of the rigid-wing rolling effectiveness, computed for a Mach number of 0.8 according to reference 2, are given as follows:

Model	m_{θ_r} (in.-lb/radian)	ϕ
50	3.25×10^4	0.81
51	2.66	.76
53	3.39	.82

The aforementioned wings are considered to possess adequate torsional stiffness for the purposes of these tests.

The maximum Reynolds number attained in these tests was of the order of 6,000,000 based on the wing chord in the flight direction.

INSTRUMENTATION

Rolling-Velocity Measurements

The time history of the rolling displacement of the RM-5 during flight is obtained by means of a small radio transmitter or "spinsonde" housed in the Plexiglas nose of the model. The spinsonde provides a continuous-wave radio frequency field which is approximately plane polarized in a plane normal to any radius drawn from the center of the antenna and of nearly spherical field strength pattern. In flight the polarized field rotates with the model about the longitudinal axis. The receiving antenna on the ground is polarization sensitive and as the polarized field rotates a low frequency signal is produced at the output of the receiver. The frequency of this signal represents twice the relative angular velocity of the model with respect to the receiving antenna. The spinsonde signal and timing and synchronization data are recorded on a film type recorder permitting the reduction of the rolling-velocity data and correlation with the flight-path-velocity measurements.

Acknowledgment is hereby made to the Langley Instrument Research Division for the development of the technique for measuring the rolling velocity of the test vehicle in flight. This work by the IRD in a large part made possible the tests described herein.

Flight-Path-Velocity and Atmospheric Measurements

The velocity along the flight path is measured by means of continuous wave Doppler radar using the technique described in reference 3. Radiosonde observations of the variation of density and temperature with altitude are made at the time of firing.

ACCURACY

The measurements shown in table I indicate the accuracy of model construction. Some of the differences obtained in the results of firings of duplicate models can be attributed to the physical differences in the models.

The accuracy of the results is estimated to be within the following limits:

Wing-tip helix angle, $\frac{pb}{2V}$		± 0.002
Drag coefficient, C_D		± 0.004
Mach number, M		± 0.01

EVALUATION OF RESULTS

The measurements made in the investigation provide time histories of flight-path velocity, Mach number, and rolling velocity. Typical curves of these quantities plotted against time are shown in figure 3. These data, for the coasting flight after burnout, are then used to obtain curves of wing-tip helix angle $\frac{pb}{2V}$ against Mach number.

The results obtained for the models covered in this report are presented in figure 4. The drag coefficients, also shown in figure 4, are computed by a method involving the differentiation of the velocity-time curve.

It will be noted that the values of $\frac{pb}{2V}$ of figure 4, computed directly from time-history data (such as shown in fig. 3), are not

steady-state values owing to the time rate of change of rolling velocity the model is experiencing, and the rolling moment of inertia of the model. With the assumptions that, at the same forward speed and Mach number, the aileron effectiveness and the twisting of the wing are unaffected by small changes in rolling velocity and that the damping moment in roll is proportional to the wing-tip helix

angle $\frac{pb}{2V}$, the following relationship between the steady-state and measured values of $\frac{pb}{2V}$ can be developed:

$$\left(\frac{pb}{2V}\right)_{\text{steady-state}} = \left(\frac{pb}{2V}\right)_{\text{measured}} \left(1 + \frac{I_x \frac{dp}{dt}}{L_D}\right)$$

where $\frac{dp}{dt}$ is the time rate of change of rolling velocity, I_x is the rolling moment of inertia of the model, and L_D is the damping moment due to rolling at the measured value of $\frac{pb}{2V}$. By use of estimated values of the damping moment, the factor $1 + \frac{I_x \frac{dp}{dt}}{L_D}$ was evaluated

for model 50a (rectangular wing plan form) in coasting flight. Except for the transonic speed range the factor was negligible, being a maximum of about 1.03 in the supersonic speed range and 0.98 in the subsonic speed range. At transonic speeds, where the greatest changes in rolling velocity are experienced, this factor (although not strictly valid in this speed range) was roughly estimated to be 1.2 at the greatest positive rolling acceleration (time, 2.6 sec, fig. 3) and 0.8 at the greatest negative acceleration (time, 2.47 sec, fig. 3). The changes in rolling velocity cited in the above example are probably the most severe which will be encountered in the course of the investigation. It is considered that the effects of inertia do not seriously influence the interpretation of the data.

It is pointed out that values of $\frac{pb}{2V}$ even when corrected for inertia effects are not direct measures of the control effectiveness, that is, the lift produced by unit control deflection. Equilibrium values of $\frac{pb}{2V}$ are determined by the equilibrium between the rolling moment supplied by the deflected control and the damping moment due to the ensuing rolling motion. Changes in the values of $\frac{pb}{2V}$ may occur by a change in either of these aerodynamic characteristics. For this

reason the measurements of $\frac{pb}{2V}$ are directly applicable only to the evaluation of the rolling capabilities of wing-control combinations. It is possible to determine the effectiveness of a particular control only by making certain assumptions with regard to the damping. For example, it is reasonable to attribute the abrupt loss in $\frac{pb}{2V}$ measured for configuration 50 (fig. 4) at transonic speeds to loss in control effectiveness, since available information indicates that the damping does not increase at these speeds.

DISCUSSION

The abrupt loss in control effectiveness at transonic speeds for straight wings determined also in previous investigations (reference 1), is clearly illustrated in figure 4 (models 50 and 51). The loss of effectiveness for the 9-percent-thick section (model 50) occurs at a Mach number of about 0.86 and for the 6-percent-thick section (model 51) at a Mach number of 0.88. A reduction of the section thickness ratio was beneficial in that the loss of effectiveness is less severe and occurs at a slightly higher Mach number. The relatively large values of $\frac{pb}{2V}$ obtained for model 51 are due in part to the fact that the aileron deflection was inadvertently slightly larger than for models 50a and 50b (table I). No attempt has been made to correct the $\frac{pb}{2V}$ data to comparable aileron deflections because the effectiveness may not be linear with aileron deflection and because the deflections were checked at only one section on each wing panel. Wing sweepback (model 53, $\Lambda = 45^\circ$) eliminated the sudden loss of effectiveness measured for the straight wings; the values of $\frac{pb}{2V}$ decrease comparatively gradually in going from subsonic to supersonic Mach numbers. It is noted that, in both the transonic and supersonic speed ranges, the values of $\frac{pb}{2V}$ obtained with the sweptback wing are considerably greater than for the straight wing of the same thickness; however, in the subsonic range the values are comparable.

Examination of the drag data presented in figure 4 shows that the Mach numbers at which the sudden loss in control effectiveness occurs for the straight wings is very near to the Mach numbers at which the sudden rise in drag coefficient occurs. It is also interesting to note the apparent relationship between the severity of the control loss and the amount of the drag increase. For the 9-percent-thick straight wing, for which the control loss was greatest, the drag

rise is greatest; for the 6-percent-thick straight wing, the control loss was less severe and is accompanied by a smaller increase in drag. For the sweptback wing, for which the loss of control in the transonic range was gradual, the drag rise is least. These relations indicate that the drag rise and loss of control effectiveness have the same origin.

CONCLUSIONS

The following conclusions are indicated from the tests reported herein:

1. An abrupt loss of control effectiveness occurred with the straight wings in the transonic speed range.
2. For the straight wings, reducing the section thickness ratio from 0.09 to 0.06 decreased the severity of the loss of control effectiveness and increased the Mach number at which the loss occurred.
3. Wing sweepback of 45° eliminated the sudden loss of effectiveness in the transonic speed range. The values of $\frac{p_b}{2V}$ obtained for the sweptback wing were greater than for the straight wing of the same thickness in both the transonic and supersonic speed range investigated.

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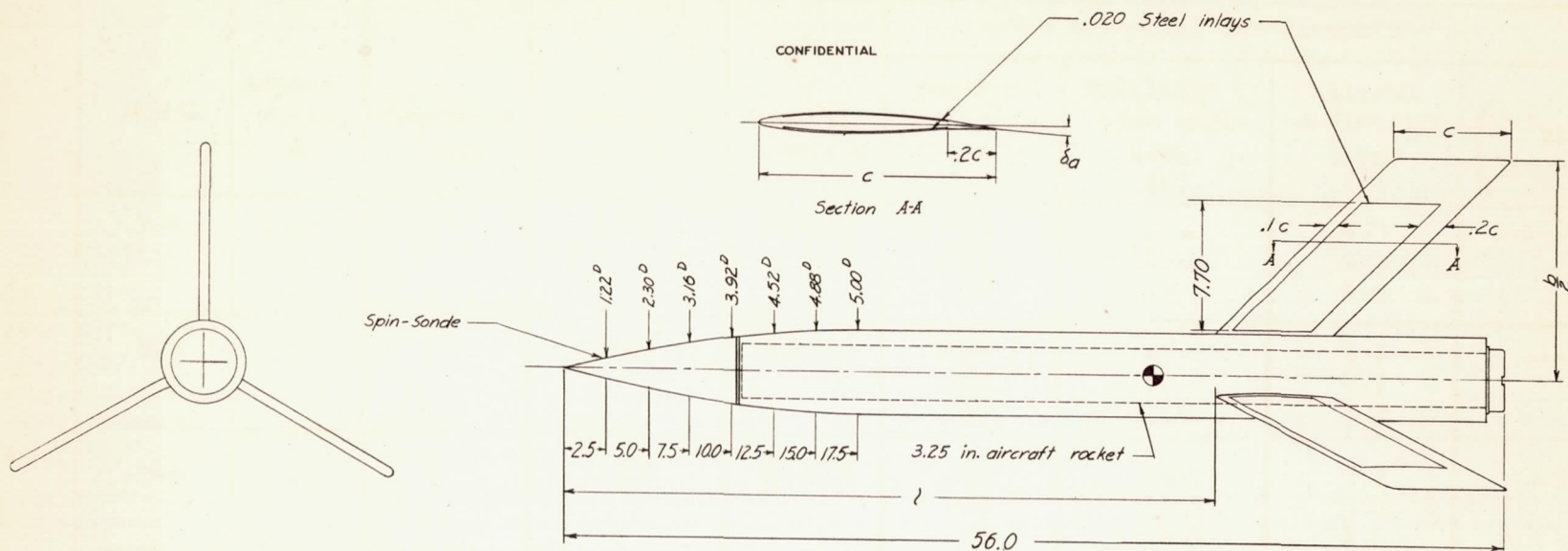
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3. Pitkin, Marvin, Gardner, William N., and Curfman, Howard J., Jr.: Results of Preliminary Flight Investigation of Aerodynamic Characteristics of the NACA Two-Stage Supersonic Research Model RM-1 Stabilized in Roll at Transonic and Supersonic Velocities. NACA RM No. L6J23, 1946.

TABLE I
GENERAL CHARACTERISTICS OF MODELS TESTED

Model	Aspect ratio, A	Sweepback (deg)	Taper ratio	Nominal section	Actual model measurements			
					Section thickness ratio (a)	Trailing-edge angle (deg) (a)	Aileron deflection (deg) (a)	$\left(\frac{I_{xx}}{\text{slug-ft}^2} \right)$
50a	3.00	0	1.00	65-009	0.098	10.0	4.5	0.1095
					.095	10.0	4.3	
					.097	9.3	4.5	
50b	3.00	0	1.00	65-009	.096	10.0	3.7	.1110
					.093	10.0	4.7	
					.090	9.0	3.7	
51a	3.00	0	1.00	65-006	.065	4.5	5.7	.1095
					.064	4.3	5.6	
					.064	4.3	4.0	
53a	3.00	45	1.00	65-009	.093	10.5	6.0	.1110
					.092	10.0	4.9	
					.090	9.0	6.0	
53b	3.00	45	1.00	65-009	.093	9.7	4.5	.1250
					.088	8.2	5.3	
					.087	8.2	5.0	

^aSections at mid-aileron span in free-stream direction for each fin of each model.



Model	Sweep-back deg	b/2 in.	c in.	l in.
50 (a & b)	0	13.11	7.07	47.59
51 (a)	do	do	do	do
53 (a & b)	45	do	do	38.94

Aileron extends over entire span
 Center of gravity is at station 35 (approx.)
 All dimensions are in inches
 Exposed area of each fin, 75 sq in.

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Figure 1.- General arrangement of RM-5 test vehicle.

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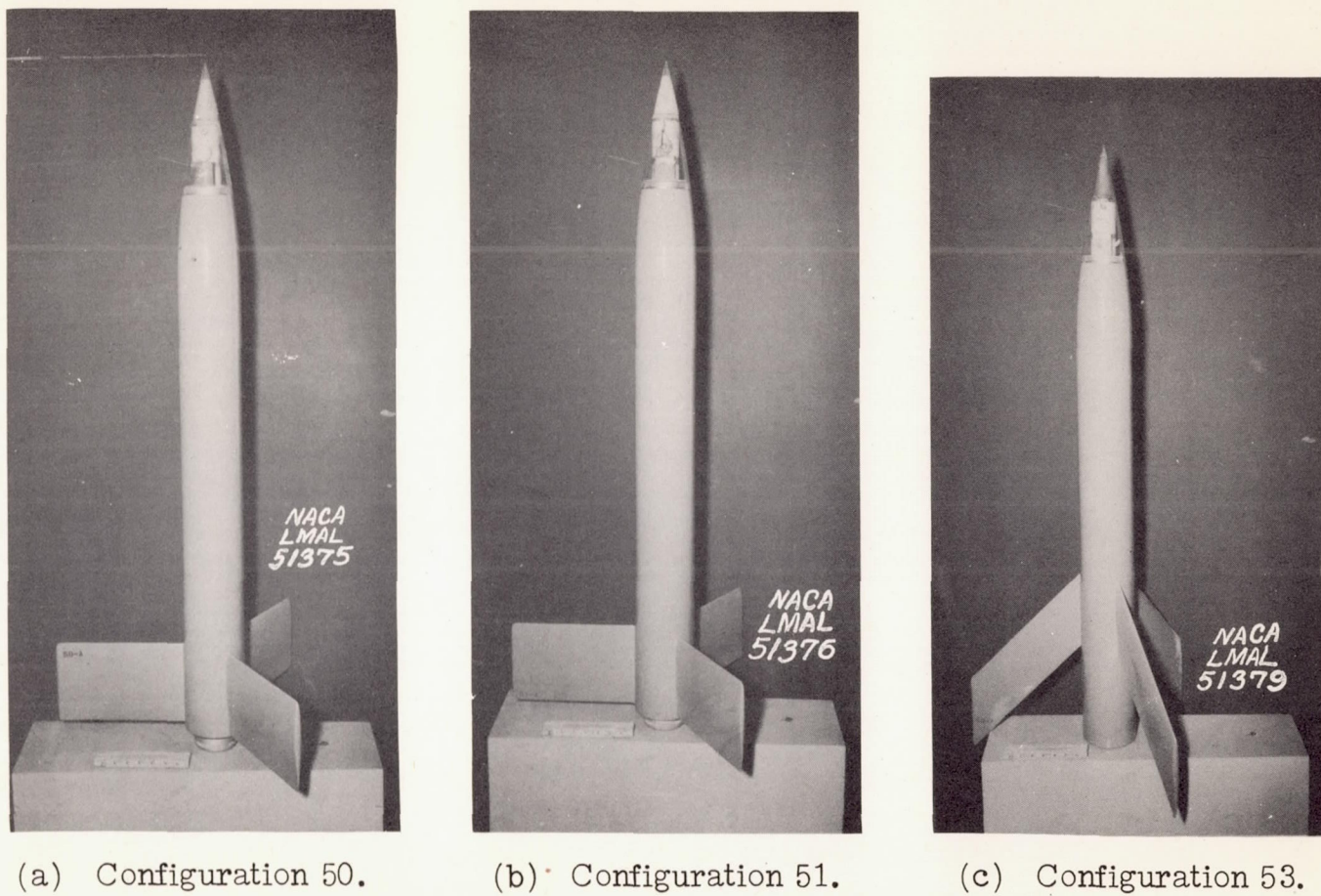


Figure 2.- Model configurations tested.

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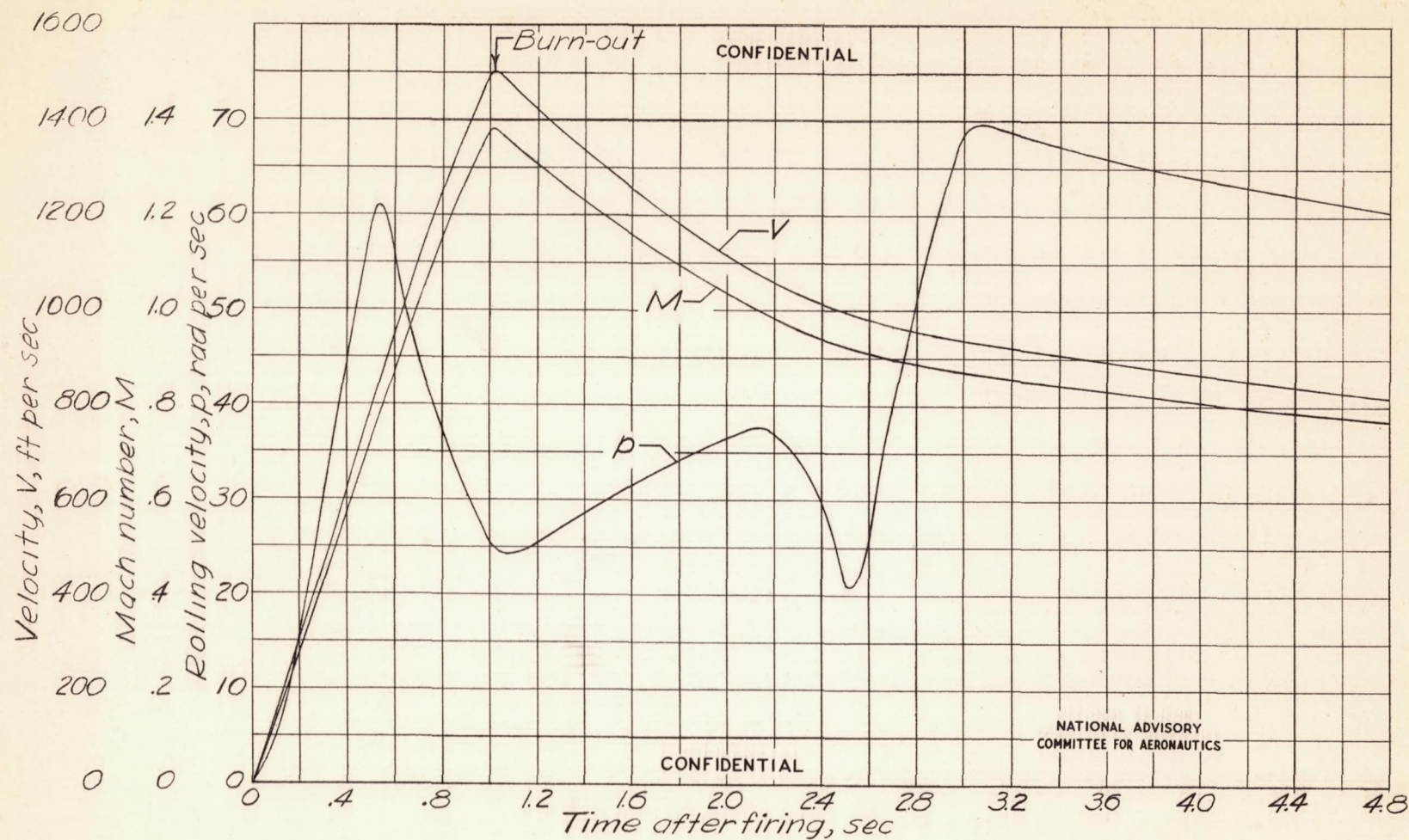


Figure 3.—Typical curves of velocity, Mach number, and rolling velocity versus time. (Model 50a).

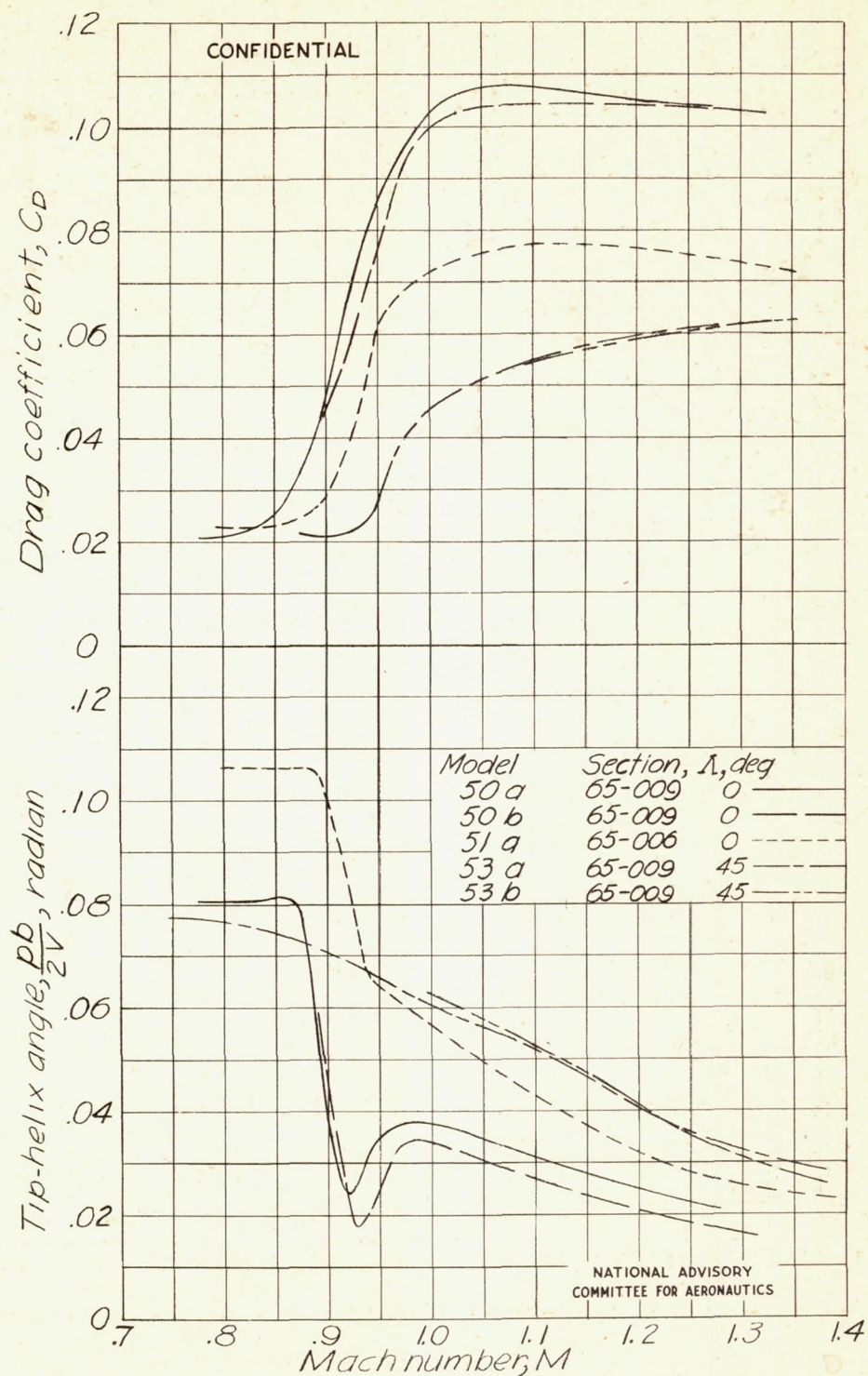


Figure 4.— Variation of tip helix angle and drag coefficient with Mach number.

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